Design and Development of a Next Generation High Capacity, 20k Pulse Tube Cryocooler for Active Thermal Control on Future Space Exploration Missions

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For future NASA exploration missions, the storage time of cryogenic propellants must extend beyond half a day, to multiple years, in order to enable projected applications such as the propulsion stages for long duration missions to asteroids and/or Mars, storage tanks on near-earth orbits and planetary destinations, long-term cryogenic propellant storage with an emphasis on hydrogen storage, and on-orbit large-scale cryogenic depots. This requires a combination of high capacity, low temperature, light weight, and highly efficient cryogenic cooling that is currently lacking. In particular, current state-of-art 20 Kelvin cryocoolers have a heat load capacity of 1 Watt at 20 Kelvin with a specific power of 180 W of heat input for each W of cooling power. However, 20 Kelvin cryocoolers with a heat load capacity of at least 5 Watts, with a specific power of approximately 100 W/W, will be required for future exploration missions. Therefore, the goals of this project are to:

1. Thoroughly design and parametrically study a complete two-stage pulse tube cryocooler (PTC) with a 5W or larger cooling capacity at 20K. This will be done using state-of-art numerical and computational tools.
2. Perform an in-depth investigation of the regenerators (which are critical components of cryocoolers) at pore and component levels, particularly with regards to the lower temperature stage regenerator which will contain filler material made from rare Earths.
3. Fabricate and test the most critical components of the designed cryocooler system.
4. Perform an in-depth experimental study of the critical components, with comparison between experimental measurements and model/simulation predictions and improvements in modeling details done at all stages.
5. Fabricate and test a prototype of the designed 5 W at 20 K cryocooler in its entirety. The constructed cryocooler will be multi-stage, and will consist of multiple heat exchangers, regenerators employing both rare-Earth materials and traditional metal fillers, pulse tube components, and corresponding inertance lines and surge volumes.
6. Concurrently with the design/demonstration/fabrication of the 5 W, 20 K cryocooler, thoroughly design and theoretically demonstrated a 20 W 20 K pulse tube cryocooler.

The 5 W at 20 K two-stage cryocooler and its low temperature regenerator will be an innovative space technology advancement and a significant leap from current state-of-art, directly useful for the propulsion stages of long duration missions and many other apllications. This technology will lead to accomplishing near-zero boil-off rates for cryogenic propellants which address NASA's Grand Challenges needs. The 20 W at 20 K cryocooler will represent an evidently larger leap from current state-of-art, and will significantly contribute to NASA's Grand Challenges needs.